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Coastal Modeling System: Dredging Module

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the implementation of a dredging module (DM) within the U.S. Army Corps of Engineers (USACE) Coastal Modeling System (CMS). The DM simulates one or more dredging operations during a CMS simulation and provides options for the dredging and placement of material. The DM may be used in studies such as estimating future dredging requirements, evaluating alternative dredging operations, and analyzing morphologic consequences of dredging operations. A coastal application at St. Marys Entrance Channel, FL, is provided to illustrate the setup procedure and demonstrate the model capability.

INTRODUCTION: The CMS, developed by the Coastal Inlets Research Program (CIRP), is an integrated suite of numerical models for simulating water surface elevation, current, waves, sediment transport, and morphology change in coastal and inlet applications. It consists of a hydrodynamic and sediment transport model, CMS-Flow, and a spectral wave model, CMS-Wave (Buttolph et al. 2006; Sánchez et al. 2011a, b; and Lin et al. 2008). The CMS is interfaced through the Surface-water Modeling System (SMS).

Dredging is one of the primary missions of USACE. Several hundred million cubic yards of sediment are dredged annually from U.S. ports, harbors, and navigation channels to maintain and improve the Nation's navigation system for commercial, national defense, and recreational purposes (USACE 2010). Dredging operations can have a significant impact on coastal morphological evolution (Stark 2012). Hence, the simulation of the coastal morphological features should also include dredging activities. In the past, dredging activities have been incorporated into CMS modeling studies by (1) interrupting the CMS simulation and modifying the bathymetry according to dredging activities and re-initializing the simulation (Beck and Legault 2012) or (2) limiting the simulation period to be within the dredging cycles (Sánchez and Wu 2011). To accurately simulate long-term coastal morphology change extending over multiple dredging cycles, a DM has been developed and implemented in the CMS. The module directly simulates dredging operations by removing and adding sediment to user-specified dredge and placement areas.

DREDGING MODULE (DM) OVERVIEW: The DM simulates the dredging and placement of material by simply adjusting the bed elevations of user-defined dredge and placement areas on the CMS-Flow grid. In the present version, the DM assumes a uniform bed composition and therefore is only recommended to be used with a single sediment size class. This limitation will be addressed in the subsequent version of the DM. There are multiple options for controlling how a dredging event is triggered, how the material is dredged, and how the material is placed. If CMS-Flow is coupled to CMS-Wave, the updated bathymetry is passed to the CMS-Wave grid at each steering interval. The DM is coupled to the hydrodynamics, waves, and sediment transport through the bed elevations. The dredging simulation can also be configured to simulate the construction of islands created through placement of dredged sediment. It is also possible to represent conditions in which the dredged sediment is placed in upland areas or in areas not represented in the CMS grid domain. A verification of the DM is presented in Reed & Reed (2014) for eight idealized test simulations to ensure correctness of input and output as well as mass conservation. The DM is not intended to simulate the details of the dredging operation since it does not simulate processes such as the suspension of sediments during dredging, hopper dredging overflow, sediment dispersal during placement, etc. The primary purpose of the DM is to represent the morphologic changes due to dredging operations and estimate future dredging requirements in response to system modifications or changes in the environmental forcing.

MODEL SETUP: Dredging simulations are organized into dredge operations. Each dredging operation is characterized by a single dredge area and one or more placement areas. Multiple dredging operations may be specified in a simulation. For each dredging operation there are multiple options for controlling how a dredging operation is triggered, how the dredged material is removed, and how the dredged material is placed. Each dredging operation can use any of the user-defined dredge and placement areas.

All dredge operations use the same dredge update interval at which the dredging and placement occur. The dredged volume is calculated as the product of the time interval and the dredging rate. The dredging update interval is the same for all operations and is specified only once. The parameter is only required for the explicit temporal solution scheme available in CMS; when the implicit scheme is used, the dredging update interval is automatically set to the hydrodynamic and sediment transport time step because this time step is relatively large.

The dredge and placement areas are defined by creating input datasets similar to a bottom-friction or hard-bottom dataset. The datasets are easily created and exported in XMDF file(s) (*.h5) in the SMS. Users should refer to the CMS User Manual for more information on how to create and export user-defined datasets (Sánchez et al. 2014). Cells within the dredge areas are assigned a depth indicating the maximum dredge depth. The dredge depth is the maximum depth to which a cell is dredged. Cells in the placement areas are assigned a value of 1. Cells outside of the dredge and placement areas are assigned a value of -999, which is the SMS convention for undefined values.

For each dredge area, the following must be defined:

1. Dredging depths dataset (also defines dredging area)
2. Criteria for triggering dredging
3. Dredging rate
4. Method for determining where to dredge first
5. Method for placement of dredge material.

The four options for triggering dredging for a scenario are the following:

1. If any cell in the source area has a bottom elevation above a threshold, as defined by the user
2. If the volume of sediment above the dredged depth is above a threshold, as defined by the user

3. If a certain percentage of the source area's bottom elevation is above a threshold, with both the threshold and the percentage defined by the user
4. Specification of a time window during which dredging can occur. Any dredged areas with elevations above the specified depth will be dredged during the specified time period. Multiple time periods can be specified.

The dredging approach defines the order in which cells are dredged to the specified depth. There are two dredging approach options:

1. During each dredging interval, the volume dredged initiates from the shallowest point in the source area first.
2. A dredging starting point is defined, and the volume dredged during each interval is taken from the cell closest to the starting point first and then progresses to cells that are farther away from the starting point. The starting point is defined by the user by specifying the cell ID that contains the starting point.

If more than one placement area is specified for a dredging operation, then one of two methods is used to determine how the dredge material is distributed amongst the placement areas. In the first approach, the placement areas are filled in the order that they are defined in the advanced cards. All dredged material is placed in the first placement area until filled and then in the second area and so on. If all of the placement areas are filled to capacity, then the dredged material is assumed to be placed out of the grid system, and that volume is recorded. In the second scenario, the percentage of dredged material allocated to each placement area is defined during each dredging interval. If any placement area reaches capacity during the simulation, the dredged material is redistributed across the remaining placement areas, based on their relative percentages. If all of the placement areas fill during a simulation, then the material is placed outside of the grid domain. It is noted that if no placement area is specified, or the allocation does not sum to 100%, the remaining dredged volume is placed outside of the grid domain.

The following must be defined in each placement area:

1. The placement limit, which is the maximum height that dredge material can be placed
2. Method for determining where to start the material placement.

There are two methods for specifying the placement limit for each placement area:

1. Placement is limited to a user-specified thickness above the bed. If the material placed in a cell exceeds the specified thickness, then no more material will be placed in that cell.
2. Placement is limited to a minimum water depth above the bed. If the material placed in a cell reduces the cell's water depth to the specified limit, then no more material will be placed in that cell.

Both options can be defined for specifying the placement limit. In that case, the more limiting condition will be used.

There are two options for determining where to start the material placement:

1. The volume dredged is placed uniformly across the placement area. Each cell is filled to the specified thickness or the placement water depth limit (also referred to as the place-

ment limit). When a cell reaches its placement limit, no more material is placed in that cell.

2. A starting point is defined in the placement area. The volume dredged is placed in the cell closest to the point, and then the placement progresses to cells that are farther away from the starting point. The user defines the starting point by specifying the cell ID. Each cell is filled to the specified thickness or the placement water depth limit.

Input cards. The dredging simulations are specified using the advanced cards in the CMS menu and the dredge and placement areas specified using the SMS interface. The cards for the DM are described in Table 1. The first card is specified once, and the remaining cards are specified for each dredging scenario in a simulation. A specific simulation may not require all the cards.

Table 1. Dredge module parameter specifications in the CMS.

Input	Format	Comments
Time interval for updating dredge algorithm	[card=DREDGING_PDATE_INTERVAL] [name=**OpTimeInt**, type=*real*, default=10] [name=**OpTimeIntUnits**, type=*char*, options=**TimeUnits**, default='min', optional=**true**]	Only used for the explicit solver. The dredge interval is set automatically to the hydrodynamic time step for the implicit solver.
Dredging operation block	[begin=DREDGE_OPERATION_BEGIN, name=**DredgeOpBlock**]	Begin a dredging operation block structure.
Name of dredging operation	[card=NAME, parent=**DredgeOpBlock**, optional=**true**]	Assign a unique name to a dredging operation.
Dredge block	[begin=DREDGE_BEGIN, name=**DredgeBlock**, optional=**false**]	Begin a dredging block structure.
Dredge area and depth	[card=DEPTH_DATASET, parent=**DredgeBlock**, optional=**false**] [name=**DredgeDepthFile**, type=*char*, default=**mpFile**] [name=**DredgeDepthPathID**, type=*char*, default=**none**]	Specify the file name and path of the XMDF file with the dredging depth dataset. A depth value of -999.0 is assigned outside of the dredge area. **mpFile** is the CMS-Flow Model Parameter (*_mp.h5) file.
Dredging method	[card=START_METHOD, parent=**DredgeBlock**, optional=**true**] [name=**DredgeMethod**, type=*char*, options=(SHALLOW,CELL), default=SHALLOW]	Specify the method used to determine the order in which cells are dredged in the source area.
Starting Location for dredging	[card=START_CELL, parent=**DredgeBlock**, optional=**false**] [name=**CellID**, type=*integer*]	**CellID** is the SMS cell ID of the starting location of the dredging operation. Only needed if START_METHOD is set to CELL.
Dredging rate for specified dredge scenario	[card=(DREDGE_RATE,RATE) parent=**DredgeBlock**, optional=**false**] [name=**DredgeRate**, type=*real*, optional=**false**] [name=**DredgeRate**, type=*char*, options=('m^3/day','m^3/hr', 'ft^3/day','ft^3/hr', 'yd^3/day','yd^3/hr',) default='m^3/day', optional=**true**]	Specify the dredging rate. The dredging rate is constant for each dredging operation.
Trigger method	[card=TRIGGER_METHOD, parent=**DredgeBlock**, optional=**false**] [name=**TriggerMethod**, type=*char*, options=(DEPTH,VOLUME,PERCENT, TIME_PERIODS), default=DEPTH]	Specify the method for triggering dredging: The options are the following: DEPTH: Dredging is triggered when the depth of a cell in the source area exceeds a depth threshold. VOLUME: Dredging is triggered when the volume of sediment above the dredge depth in the source area exceeds a volume

		threshold. PERCENT: Dredging is triggered when the a percentage of the cells in the source area exceed a threshold depth. TIME_PERIODS: Dredging is triggered for user-specified time periods.
Trigger depth	[card=TRIGGER_DEPTH, parent=**DredgeBlock**, optional=**false**] [name=**TriggerDepth**, type=*real*] [name=**TriggerDepthUnits**, type=*char*, options=**LengthUnits**, default='m']	Specify the dredging trigger depth. If specified, **TriggerMethod** is set to DEPTH.
Trigger volume	[card=TRIGGER_VOLUME, parent=**DredgeBlock**, optional=**false**] [name=**TriggerVolume**, type=*real*] [name=**TriggerVolumeUnits**, type=*char*, options=**VolumeUnits**, default='m^3']	Specifies the dredging trigger volume. If specified, then **TriggerMethod** is set to VOLUME.
Dredging time periods	[card=DREDGE_TIME_PERIODS, parent=**DredgeBlock**, optional=**false**] [name=**Ntp**, type=*integer*] for(i=1:**Ntp**, [name=**Ts**(i), type=*real*] [name=**Tf**(i), type=*real*]) [name=**DredgeTimePeriodUnits**, type=*char*, options=**TimeUnits**, default='hr']	Specifies dredging time periods. If specified, then **TriggerMethod** is set to TIME_PERIODS.
Placement distribution method	[card=DISTRIBUTION, parent=**PlacementBlock**, optional=**false**] [name=**PlaceDistMeth**, type=*char*, options=(PERCENT,SEQUENTIAL), default=SEQUENTIAL]	Specifies the method for triggering dredging. The two options are the following: PERCENT: A percentage of the dredge material is assigned for each placement area. The percentages of all placements must sum up to 100. SEQUENTIAL: The placements are filled sequentially in the order as listed.
Dredge block	[begin=DREDGE_END, name=**DredgeBlock**]	End a dredging block structure.
Placement block	[begin=PLACEMENT_BEGIN, name=**DredgeBlock**, optional=**false**]	Begin a placement block structure.
Placement area	[card=AREA_DATASET, parent=**PlacementBlock**, optional=**false**] [name=**DredgeAreaFile**, type=*char*, default=**mpFile**] [name=**DredgeAreaPathID**, type=*char*, default=**none**]	Specifies the file name and path of a XMDF file for the placement area. The placement area is given by nonzero values in the dataset. **mpFile** is the CMS-Flow Model Parameter (*_mp.h5) file.
Placement method	[card=PLACEMENT_METHOD, parent=**DredgeBlock**, optional=**false**] [name=**DredgeMethod**, type=*char*, options=(UNIFORM,CELL), default=UNIFORM]	Specifies the method for placement. The two options are the following: UNIFORM: The dredge material is placed uniformed over the placement area. CELL: The dredge material is placed starting at the user-specified point (location).
Percentage of material from dredge area	[card=DISTRIBUTION_PERCENTAGE, parent=**PlacementBlock**, optional=**true**] [name=**PlacementPercent**, type=*real*]	Specifies the percentage of material from the dredge area assigned to placement area. Only needed if the DISTRIBUTION card is set to PERCENTAGE.
Starting location for placement	[card=START_CELL, parent=**PlacementBlock**, optional=**false**] [name=**CellID**, type=*integer*]	Specifies the SMS cell ID, **CellID**, of the starting location of the placement. Only needed if START_METHOD is set to CELL.
Limit on depth of disposed materi-	[card=DEPTH_LIMIT, parent=**PlacementBlock**,	Specifies the depth below water surface that material placement cannot exceed.

al in placement areas	optional=**false**] [name=**PlacementLimit**, type=*real*, parent= **PlacementBlock**) [name=**PlacementLimitUnits**, type=*char*, options=**LengthUnits**, default='m']	
Limit on height of disposed material in placement areas	[card=THICKNESS_LIMIT, parent=**PlacementBlock**, optional=**false**] [name=**ThicknessLimit**, type=*real*, optional=true]) [name=**PlacementLimitUnits**, type=*char*, options=**LengthUnits**, default='m']	Specifies the maximum thicknesses above initial bed layer that placed material cannot exceed.
Placement	[end=PLACEMENT_END, name=**DredgeBlock**]	Ends a placement block structure.
Dredge operation	[endn=DREDGE_OPERATION_END, name=**DredgeOpBlock**]	Ends a dredging operations structure.

Output. The DM produces the following output:

1. Setup File: The DM setup file, called dredge_module_setup.txt, is written at the beginning of the CMS simulation when dredging is turned on and contains a summary of the dredge scenarios and parameters defined in the advanced cards.
2. Global Output: When a dredging scenario is defined, global output will be generated for the depth and morphology arrays. If sediment transport is active, the output will occur at the same intervals specified for morphology output. If sediment transport is not active, the morphology output will be written at the same interval as the water elevation output.
3. Time-Series Output: A time-series output file in the comma delimited ASCII format will be generated for each dredging scenario defined in the simulation with the name DredgeDetailsOpNum_1.csv where the "_1" specifies the dredge scenario. The scenarios are numbered by the order in which they are defined in the advanced cards.

EXAMPLE: The St. Marys Entrance Channel extends 17.4 kilometers (km) (10.8 miles) offshore to the St. Marys River Entrance. The channel continues into Cumberland Sound up to Kings Bay Naval Submarine Base for a total length of 33.5 km (20.8 miles) (Figure 1). Presently, the channel is maintained at 15.5 meters (m) (51 feet [ft]) relative to mean low water (MLW) plus 3 ft of advanced dredging. The average annual dredged volume for the entrance channel since 1989 is approximately 968,000 cubic yards/year (yd^3/year) with a range of 44,000 to over 3,000,000 yd^3/year.[1]

The CMS flow and wave models were configured to simulate dredging activities in the St. Marys Entrance Channel (i.e., the offshore portion of the channel). Bathymetry data were obtained from NOAA's National Geophysical Data Center (NGDC) web site (NGDC 2014) for St. Marys Entrance, the adjacent offshore area, and in Cumberland Sound. A telescoping grid was constructed

[1] Rosati, J. D., T. Beck, R. Thomas, and L. Dunkin. 2013. U.S. Navy FCA shoaling study: NSB Kings Bay, FL. Unpublished technical report.

with variable grid cells ranging from 50 to 500 m (1640 ft) (Figure 1a). A color contour map of the bathymetry is also shown in Figure 1b, and the entrance channel is visible in the figure. The channel depths were set to 15.5 m (51 ft) at the beginning of the simulation.

A 1-year simulation for 2008 was used for the example. The model was forced with tide constituent data using the tidal consistent database available via SMS. Wind data were obtained from the NOAA meteorological station at Fernandina Beach (Station 8720030) (NDBC 2014). A CMS wave model was also configured for the same domain as the flow grid using constant 200 m grid spacing. Wave data from Wave Information Study (WIS) station 63401 (WIS 2014) were used for input to the wave model.

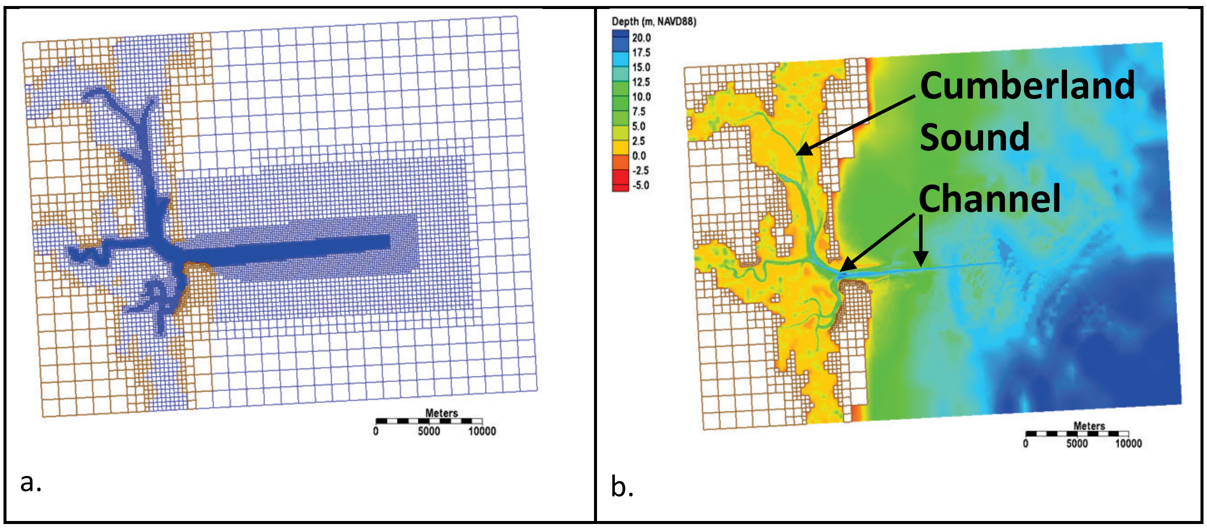

Figure 1. (a) CMS-Flow computational grid and (b) color-contour map of bathymetry for St. Marys Entrance, FL.

The flow and wave models were run using the implicit temporal scheme with the inline steering (coupling between flow and waves) option with a hydrodynamic time-step of 10 minutes (min), and a steering interval of 1 hour (hr). The DM was configured to simulate dredging of the outer channel. The dredging and the placement areas are shown in Figure 2.

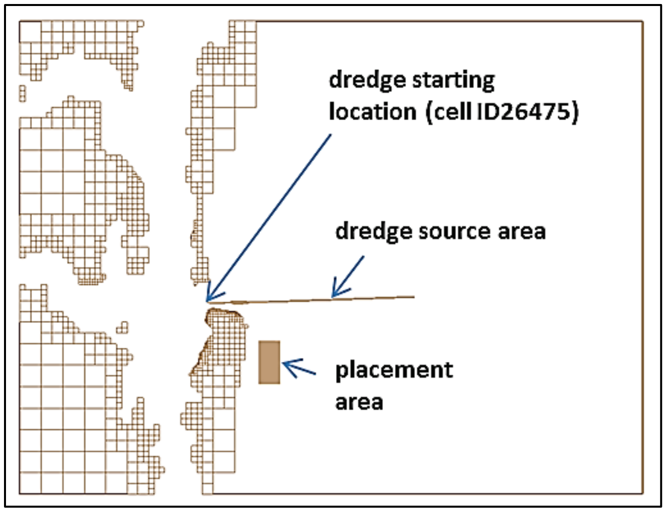

Figure 2. Dredge and placement areas and the dredge starting location.

The advanced cards used to activate the DM are listed in the example below:

```
!Dredging Module Input Cards
DREDGE_UPDATE_INTERVAL          900.0 'sec'
DREDGE_OPERATION_BEGIN
   NAME                         "MaintDREDGE"
   DREDGE_BEGIN
      DEPTH_DATASET             "Dredgearea.h5" "Datasets/Dredge_Area"
      DREDGE_RATE               20000.0 'm^3/day'
      START_METHOD              CELL   !SHALLOW
      STARTING_CELL             26475
      DISTRIBUTION              SEQUENTIAL !PERCENT | SEQUENTIAL
      TRIGGER_METHOD            DEPTH !DEPTH | VOLUME | PERCENT | TIME_PERIODS
      TRIGGER_DEPTH             14.0 'm'
   DREDGE_END
   PLACEMENT_BEGIN
      AREA_DATASET              "Dredgearea.h5" "Datasets/Placement_Area"
      START_METHOD              UNIFORM !STARTING_POINT
      DEPTH_LIMIT               3.0 'm'
   PLACEMENT_END
DREDGE_OPERATION_END
```

The file containing the identification of cells in the dredged and placement areas is “DredgeAreas.h5” with paths “Datasets/DredgeArea” and “Datasets/PlacementArea.” The dredge depth was set to 15.5 m (51 ft), and the triggering approach was set to the DEPTH method with a depth of 14.0 m (46 ft). The dredging rate was 20,000 cubic meters/day (m^3/day) (26,159 yd^3/day). The dredging started at the river entrance (cell ID 26475) and proceeded offshore. There was a single placement area. Dredged material was placed uniformly in each cell in the placement area and continued for each cell until the prescribed depth limit of 3.0 m (9.84 ft) was reached.

A time-series plot of the dredging activities is shown in Figure 3. The relative offshore wave height during the simulation is shown in grey. The maximum height was 5 m (16.4 ft), and the sudden increase in the channel sediment volumes correlates well with the large wave events. The black dashed line (volume in channel) represents the sediment volume that is above the specified dredge depth in the entire dredge source area. The red line (volume ahead of dredge) is the sediment volume that has not been dredged yet in the section of the channel. For the first 33 days, these volumes are identical because dredging has not started. At day 33, the depth in the channel goes below the triggering depth of 14.0 m (45.93 ft) and dredging begins. The volume ahead of the dredge is the volume remaining to be dredged and decreases as the dredge progresses through the source area. The total volume in the dredge area also decreases but at a slower rate since sedimentation continues in the areas of the channel already dredged (i.e., behind the dredge). The sediment volumes occasionally increase in response to large wave events. The dredge reaches the end of the source area on day 93, when the sediment volume ahead of the dredge is reset to the same value as the total volume in the channel. At this point, the total dredged volume is approximately 1,150,000 yd^3 (879,238 m^3). However, since sedimentation has been occurring *behind the dredge*, the triggering criteria of 14 m depth is exceeded only 1 week later, and the dredging cycle starts again.

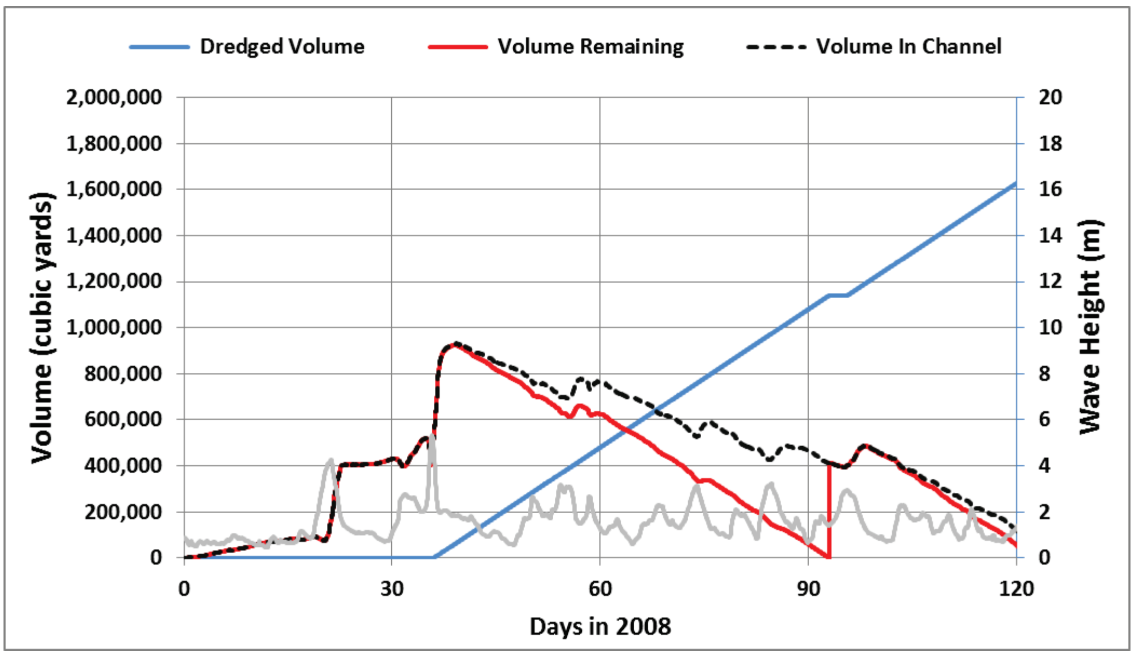

Figure 3. Volume of sediment in channel and cumulative dredged volume as a function of time, St. Marys Entrance.

SUMMARY: A DM has been developed and implemented in the CMS. The module significantly enhances the capability of the model to support the USACE dredging operations at navigation channels by directly simulating dredging and placements within a CMS simulation. This allows the CMS to run over multiple dredging cycles and includes the morphological feedback that dredging produces on the morphology change. The implementation procedure for dredging operations was described, and an example simulation for conditions at St. Marys Entrance Channel, FL, has been provided to demonstrate the setup and results. Future enhancements to the DM include the representation of nonuniform sediments, spatially variable placement thicknesses or depths, and a user-friendly interface within the SMS.

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ADDITIONAL INFORMATION: Questions about this CHETN can be sent to Dr. Alex Sánchez at (601-634-2027), FAX (601-634-3433), or e-mail: *Alejandro.Sanchez@usace.army.mil*. An electronic copy of this document is available at *http://chl.wes.army.mil/library/publications/chetn/*. This Technical Note should be referenced as follows:

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